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PROTECTION FROM PRIMARY COSMIC RADIATION AND PROTONS OF THE EARTH'S INNER RADIATION BELT

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DATA PROCESSING SYSTEMS IN SPACE BIOLOGY

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ABSTRACT

Changes in the needs of experimental information and the use of data processing, especially probability-statistical methods, are discussed. Investigative and control systems of data processing are discussed for unique space biology conditions, with Vostok flights used as examples. Progress is shown in automating information analysis, such as expressing biological indicators by mathematical equations. Present needs and corrections in space biology, such as information theory, are shown.

Modern biology moves more and more from the qualitative evaluation /100* of phenomena to the analysis of their quantitative characteristics. There has been a substantial change in the requirements for measurements carried out during scientific experiments. The experimental information obtained is subjected to a more extensive and intensive processing and in recent times electron computers have been used for this purpose. As a result of this trend, data processing systems are being used more and more (ref. 1). The probability-statistical methods of analysis play an important role in the processing of information. The relatively new field of space biology is concerned with the collection of information under flight conditions in cosmic space or in laboratory experiments under extreme conditions. In space biology each scientific experiment is unique to some extent and the quantity of information is limited. Therefore, the problem of collecting and processing scientific information becomes very important.

In space biology two types of data processing systems are differentiated: investigative systems and control systems. The information obtained by investigative systems is used in the biological study of factors which react on the living organism during space flight (acceleration, weightlessness, radiation and others), and the study of cosmic space as a habitable environment. This information is quite basic for constructing hypotheses and theories in space biology. The systems of medical control are designed to obtain operational biological information necessary to provide for flight safety. This involves a minimum number of measurements with maximum reliability. The first space flights were of an experimental nature and the data processing systems simultaneously performed the functions of control and investigation. Apparently, in the future the investigative and control systems aboard spacecraft

*Numbers given in the margin indicate the pagination of the original foreign text.

will be different from the standpoint of generated information, operating time, selection of parameters, structural peculiarities, etc.

Figure 1 shows the block diagram of data processing systems used to obtain biological data in laboratory experiments (a) and during the flight of the "Vostok" spacecraft (b). The basic units of these systems are the sensors, the amplifying and measuring units and the recording devices which feed information to the radio telemetry system when information is transmitted from the spacecraft to Earth.

It is quite characteristic of space biology that the flight and laboratory experiments are associated with a large number of measurements with a limited amount of time available for processing the data. /101

Existing data processing systems represent data in the form of curves which directly reflect the flow of a process with time. This is a traditional approach in biology although it requires considerable effort and time to extract the necessary information. Therefore, it is quite important to present information in a form suitable for rapid use by medical personnel and to apply probability-statistical methods to extract the maximum amount of useful data.

To solve the above problems, the data processing systems contain automatic processing units. Depending on the nature of the experiment and the operating conditions of the equipment these units may be aboard the spacecraft or they may be incorporated in the ground radio telemetry station and may operate together with laboratory equipment (fig. 2).

In the automatic processing of data, the necessary calculations are carried out and the information is presented in condensed and generalized form. In essence this process may be called the process of coding. However, it would be desirable to present the results of data processing in the form of diagnoses--conclusions based on the logical analysis of all measurable indicators and their deviations. Thus the data processing systems should include electronic diagnostic machines which would develop the diagnostic codes when information is fed to their inputs. In space biology there is a series of additional conditions for the operation of such a machine, specifically: a necessity for a direct introduction of data from subjects into the automatic processing units; the criteria for evaluating data obtained under various flight conditions are insufficiently developed; it is necessary to take into account the capabilities of a telemetering link.

The problem of automating the scientific analysis of biological information is of tremendous interest not only for space biology. First steps in this direction have been taken in our country and abroad (refs. 2,3,4,5). Information has been published on the application of computer technology in space medicine (refs. 6,7,8). However, for the data processing systems to operate automatically it is necessary to conduct a very large amount of work to express biological concepts in mathematical form and to determine the relationships which describe the behavior of biological systems. This work is only now starting and it is important to note its basic directions as they apply to the problems of space biology. First it is necessary to study /102

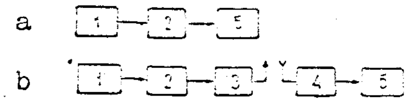

Figure 1. Data processing systems in space biology. a, laboratory conditions; b, during space flight: 1, sensors; 2, amplifying and measuring equipment; 3, radio telemetry system aboard the spacecraft 4, ground radio telemetry systems; 5, recording device.

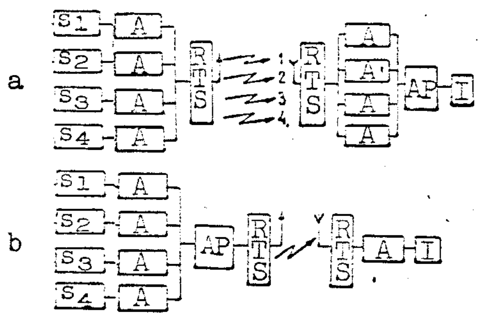

Figure 2. Automatic processing of medical information: a, at the ground; b, aboard spacecraft: S, sensors; A, amplifiers; RTS, radio telemetry system; AP, automatic processing unit; I, indicator of output data.

thoroughly the normal variations in the investigated biological indicaters and to express them by statistically proven numerical values and mathematical equations. Thus, for example, an effort has been made to express in mathematical form the equations for the variation in the pulse of a cosmonaut during his training in a centrifuge as a function of the applied acceleration.

It is also necessary to establish a correlation between different biological indicators and to investigate the diagnostic value of disrupted correlations when the values of individual parameters are retained. Thus, during the space flight of G. S. Titov vestibular disruptions were noted which were not accompanied by any pathological deviations of the pulse and of respiration. The autocorrelation function for the pulse frequency in this case changed its nature and the variation factor of the parameter also increased (fig. 3).

A promising method in the development of automatic data processing systems in space biology is the mathematical simulation of the reactions of the living organism to different factors of space flight. The problem of simulation in biology is considerably more complicated than in technology. This is due, first of all, to the extremely complex relations between the elements of a biological system and in the second place to the insufficient level of our knowledge for describing biological processes mathematically. The simulation method is only now being applied in biology, and the first experiments in this direction have shown the undisputed usefulness of this work.

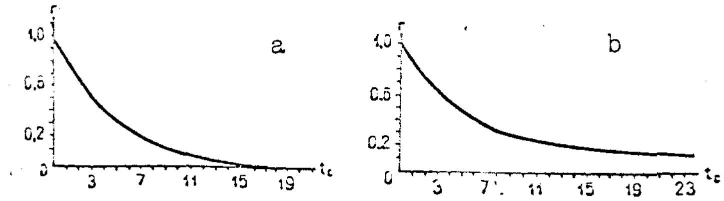

Figure 3. Autocorrelation function for pulse rate of G. S. Titov before launch (a) and in weightlessness (b).

Data have been published on the use of mathematical simulation of the greater circulation for the analysis of the effect produced by certain pharmacological methods on the cardiovascular system (ref. 9) and the simulation of blood flow in upper aortas (ref. 10). However, in space biology the use of simulation at this time is inadequate. We can point out two basic directions for the development of simulation in space biology.

1. The development of mathematical models of physiological processes for investigative purposes, i.e., for the confirmation of hypotheses on the physiological mechanisms of space flight factors as they act on an organism and the study of these mechanisms. This problem includes the simulation of the functions of individual organs and systems, for example, the simulation of cardiac functions, functions of vessels and of the cardiovascular system as a whole under the action of acceleration. The mathematical relationships determined experimentally which describe the processes and the functional interrelations in the operation of organs and systems make it possible to develop additional criteria for evaluating the condition of a cosmonaut from the limited number of recorded physiological indicators.

2. The development of mathematical models for control and prediction of changes in the state of the cosmonaut taking into account the characteristics of external factors and the continuous physiological information. Such models may be obtained by a synthetic generalization of the results of /103 physiological simulation and the results of mathematical analysis of data obtained during observations on a man under laboratory conditions and in space flights. This would make it possible to diagnose on the ground, the probable deviations in the state of the cosmonaut during different periods of time under different combinations and extent of external factors. The use of simulation in the control process would make it possible to evaluate reliably the diagnostic value of recorded physiological information, to establish the variation of functions which border on pathology and to establish the optimum variations of actions.

The problem of the biological simulation of space flight includes a large number of technical problems associated with the design of special measuring, recording and simulating devices.

In the process of accumulating data necessary for the design of models, valuable results may be obtained by conducting experiments with animals. In this case, one of the basic requirements for the data processing systems is the simultaneous recording of a large number of functions with sensors placed on the surface of the body (ECG sensors, respiration sensors) as well as inside the organism (electrodes, inserted into different regions of the nervous system, probes in cardiac cavities and in blood vessels, etc.).

As the mathematical relationships which describe the functions and interrelations of organs are established, it becomes necessary to utilize comprehensive measurement systems and simulating devices. In these systems the signal which is picked up from some organ is applied to the simulating device which reproduces the function of another organ associated with the first. An example of this is equipment which simulates the variation in cardiac contraction rate under the action of respiration (ref. 11), or the above model of blood circulation in aorta branches.

Finally the use of simulation for predicting and controlling the state of the cosmonaut involves the design of complicated measuring systems and computers taking into account all the possibilities and limitations produced by conditions of space flight.

For space biology, where the collection of a large amount of statistical information is difficult because the number of experiments, particularly those conducted in flight, is limited, it is extremely important to develop methods of extracting the maximum amount of information from a minimum amount of data. The measurement system must reproduce the entire spectrum of values from individual measurements and must construct a continuous graph of the investigated function. Then by expressing the function in the form of an equation and by solving it for some pre-assigned interval of time we can predict conditions. However, it is necessary to constantly correct the equations in accordance with new information which is received. As we have already pointed out, the initial prediction may be carried out by a mathematical model. Then the data processing system must only perform the function of a continuous comparison of the actual state of the cosmonaut with his computed state and transmit only the difference between these values over the telemetering link. Since the deviations in this case can be rather small, the accuracy of measurement becomes very significant. The theoretical calculation of the permissible errors may be made by taking into account several allowable physiological deviations. Thus the error in measuring the body temperature must not exceed 0.3-0.5 degrees, while the pulse accuracy must be within 3-5 strokes/min.

In transmitting measured data from the spacecraft to ground, definite limitations are encountered due to the capacity of the telemetering channels. By transmitting only the difference between the value of a function and its predicted curve we can substantially reduce the loading of the tele- /104
metering link. Other methods of transmitting a large amount of information over low capacity channels are associated with the automatic selection of signals according to a definite criterion, with differentiation and integration of investigative functions, and with correlation analysis. Thus, in the development of data processing systems the role of information theory is quite significant.

The reliability of bio-medical equipment which collects information is quite important. The equipment must remain operative when subjected to accelerations and vibrations, high and low temperatures, cosmic radiation and vacuum. It must be stable during the entire period of space flight, which can last for months or even years. In this case the requirements with respect to weight and energy consumption are quite stringent since the performance characteristics of a spacecraft are always limited.

The reliability of bio-medical measurements is associated with the solution of technical and biological problems. Such problems are: the selection of the methods of measuring and the design of sensors, the selection of the best method of placing sensors on the subject and the development of a measurement program--all this determines the reliability of the data processing system in recording biological processes. The methods of measurements and the sensors for medical control must be designed for prolonged use on the subject, so that it is possible to perform continuous and periodic control and also control at any instant of flight as necessary. The sensors must not produce undesirable sensation or interfere with the normal activity of a cosmonaut. A large number of recorded physiological parameters requires the development of portable sensors. The necessity that they be installed and adjusted by the flight crew during space flight raises the requirements for their standardization and simplicity and consequently their reliability.

It is necessary to provide for the monitoring of cosmonauts when they move freely. This means that the introduction of information from sensors into amplifying measuring devices must be achieved by means of radio channels and not with wires (fig. 4). Systems of this type are called small telemetry in space biology to differentiate them from "large" telemetering systems linking the ship with the earth. At the present time the transmission of biological information from a freely moving subject is undergoing development in sport and clinical medicine and in animal husbandry (refs. 12,13,14,15, and 16). Similar systems may be used in space biology with minor modifications to satisfy the requirements of transferring information over very short distances for a prolonged period of time.

Our attention should be directed towards the development of special miniature radio telemetry systems for investigating small animals during their free movement. In this case the sensors, amplifiers and transmitters are secured on the animal by implanting them into the tissue. This provides for an increased reliability of such systems. Some prospects of improving the reliability of data processing systems are opening up in connection with work in the field of bionics which applies the principles of information processing in the sensing organs and the nervous systems of animals to engineering information systems.

Thus the development of space biology poses a series of complex problems to the investigators. These problems are both of a biological and technical nature. We have considered only some of the problems associated with the processing of biological information, the simulation and reliability of equipment.

$$\underbrace{\boxed{S}-\boxed{A}-\boxed{T}}_{\text{on cosmonaut}} \quad \underbrace{\boxed{Re}-\boxed{AM}-\boxed{RS}}_{\text{on craft}} \quad \underbrace{\boxed{RS}-\boxed{R}}_{\text{on ground}}$$

Figure 4. Small telemetry aboard spacecraft. S, sensor; A, amplifier; T, transmitter; Re, receiver; AM, amplifying and measuring equipment aboard the spacecraft; RS, radio telemetry system aboard the ship; R, recorder.

The success of their solution depends to a large extent on the development of data processing systems which satisfy the biological requirements of space flight.

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